**Original Article**

# Title: Epidemiological Transition in Physical Activity and Sedentary Time in Children

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## ABSTRACT

**Background:** The purpose was to determine if moderate-to-vigorous physical activity (MVPA) and sedentary time varies across levels of social-economic status (SES) in countries at different levels of Human Development Index (HDI) in children, consistent with the theory of epidemiological transition.

**Methods:** Data from 6,548 children (55% girls) 9-11 yrs from 12 countries ranging in HDI were used in this analysis to assess MVPA and sedentary time (measured using ActiGraph accelerometers) across levels of within-country SES. Least-square means were estimated separately for boys and girls at the estimated $10^{th}$, $50^{th}$, and $90^{th}$ percentiles of HDI for the sample.

**Results:** For boys, time in MVPA was negatively associated with SES at the $10^{th}$ and $50^{th}$ percentiles HDI (both $p<0.002$). For girls, time in MVPA was negatively associated with SES at $10^{th}$ and $50^{th}$ percentiles HDI (all $p<.012$); and positively related with SES at the $90^{th}$ percentile ($p=.044$). Sedentary time was positively associated with SES at the $10^{th}$ percentile HDI for boys ($p=.031$) but not for girls.

**Conclusions:** Results support the possibility of an epidemiological transition in physical activity, with lower levels of MVPA observed at opposite levels of SES depending on the HDI percentile. This phenomenon was not observed for sedentary time.

## Introduction

The theory of epidemiologic transition, which characterizes long-term trends and patterns in morbidity and mortality associated with stages of human development,[1] has been applied to understand the emergence of obesity in low to middle income countries.[2, 3] Human development is commonly assessed at the country level with the Human Development Index (HDI), a composite statistic of life expectancy, education, and per capita income indicators. As countries transition from lower to higher levels of HDI, there are often consequences with respect to lifestyle behaviors, such as decreases in physical activity[4] and increases in the consumption of "Western" style diets.[5] For example, using cross-sectional data, it was previously reported that among children, obesity prevalence, body fat percentage, and BMI z-scores increased linearly across levels of within-country SES (defined by household income) in countries at lower levels of HDI ($10^{th}$ percentile), but decreased linearly with higher SES in countries at higher levels of HDI ($90^{th}$ percentile).[6] Although long term longitudinal observations are needed to confirm this epidemiological transition of obesity within countries, cross-sectional data comparing countries at different levels of HDI can be indicative of epidemiological transitions related to obesity and lifestyle behaviors.

While a number of studies have investigated the influence of SES on obesity and the presence of an epidemiological transition for obesity.[5, 7-10] only a limited number of multi-country studies have attempted to investigate the effects of human development on levels of physical activity.[4, 11] For example, Shoham et al.[11] investigated the association between car ownership by adults (as a proxy indicator of SES) and objectively measured moderate-to-vigorous physical activity (MVPA) among 5 countries at different HDI levels and found that those without cars accumulated more MVPA, independent of the HDI of the country. It is

77 possible that children's physical activity (particularly MVPA) and sedentary time can be
78 associated with SES, and this relationship may differ by country level of human development.
79 Some studies have documented associations between SES and physical activity among
80 children,[12] but the majority of those studies used questionnaire-based estimates of physical
81 activity and were conducted in a single high-HDI country. Sedentary time is also of interest in
82 this age group because it can have detrimental health effects. Studies tend focus on the amount of
83 time spent watching TV or using other types of electronics with screens (i.e., computers, tablets,
84 phones) with limited information on objectively measured sedentary time.[13, 14] To our
85 knowledge, no study has investigated how objectively-measured estimates of children's MVPA
86 and sedentary time relate to SES across countries of varying levels of HDI. Thus, the purpose of
87 this study was to determine if children's objectively measured time in MVPA and sedentary time
88 vary across levels of SES in countries at lower, middle, and higher levels of HDI, in accordance
89 with the theory of epidemiological transition. It was hypothesized that objectively measured time
90 in MVPA decreases linearly across within-country SES levels at the estimated 10$^{th}$ percentile of
91 HDI, but increases linearly across within-country SES levels at the 90$^{th}$ percentile of HDI. It was
92 also hypothesized that a similar but reverse relationship exists for objective measured sedentary
93 time.

94 **Methods**

95 Study design and participants

96 The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE)
97 was a multi-national cross-sectional study that collected objectively-measured physical activity
98 and sedentary time data on children from urban/suburban study sites in 12 countries. The study
99 sites included cities in Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya,
100 Portugal, South Africa, the United Kingdom, and the United States. The 12 sites included in

ISCOLE were in countries ranging from low (0.509, Kenya) to very high (0.929, Australia) HDI at the time of data collection.[15] Detailed information about the design, standardized methods and accelerometry procedures used in ISCOLE has been previously published, including open access publication of a detailed Manual of Operations.[16, 17] For this reason, only those procedures directly related to this study are presented here.

The Institutional Review Board at the Pennington Biomedical Research Center (coordinating center) approved the overarching ISCOLE protocol, and approval was also obtained for each participating institution with their respective Institutional/Ethical Review Boards. Written informed consent was obtained from parents or legal guardians, and written child assent was also obtained as required by local Institutional/Ethical Review Boards before participation in the study.

Each study site was responsible for recruiting at least 500 children. The primary sampling frame was schools, which was typically stratified by an indicator of SES in order to maximize variability within sites.[16] From the initial sample of 7,372 participants, 31 were excluded because they did not have BMI data and a further 793 participants did not have valid accelerometer data (described below). The final analytical sample consisted of 6,548 children aged 9-11 years (55% girls). Data were collected between September 2011 and December 2013 when children were attending school and excluded major holidays.

Procedures

As part of the standardized and rigorous ISCOLE protocol, the same instruments and data collection procedures were used in all sites. All research staff attended a training session and passed a certification test to be able to collect data.

*Physical activity and sedentary time*

Children were asked to wear an ActiGraph GT3X+ accelerometer (ActiGraph LLC, Pensacola, FL, US) for at least 7 consecutive days 24 h/day (removing only for water-related activities) attached to an elasticized belt and worn at the waist positioned at the right mid-axillary line. Data were collected at a sampling frequency of 80 Hz, and subsequently downloaded using ActiLife Software (version 5.64 or later, ActiGraph LLC) with the low-frequency extension filter enabled. Because the accelerometer was worn for 24 h/day, it was necessary to identify nocturnal sleep episode time distinct from waking non-wear time, and this was done using a 60 sec epoch and published automated algorithms.[18, 19] After exclusion of the nocturnal sleep episode time, non-wear time was determined as any sequence of at least 20 consecutive min of zero activity counts.[20] Once nocturnal sleep episode time and non-wear time were computed, time spent in MVPA, and sedentary time was estimated using the Evenson cut-points.[21] Children were only included in this analysis if they had ≥4 days of monitoring with at least 10 h/day of waking wear time, including at least 1 weekend day.[22]

*Household Income*

Parents/guardians completed a questionnaire which included household income levels in a single question offering eight to ten country-specific response categories locally determined by each site. For analysis, the multiple household income categories that varied among countries were collapsed into four ranked levels that approximated quartiles and ensured the most balanced distribution possible within each country. The values of each level have been previously published.[6]

*Country Human Development Index*

Consistent with to our previous publication,[6] values for the 2011 HDI[15] corresponding to estimated 10$^{th}$, 50$^{th}$, and 90$^{th}$ percentiles within the ISCOLE sample were chosen to represent

lower, middle, and higher levels of human development. Percentiles were calculated based on weighted averages. The use of sample-based percentiles ensured that the results were not extrapolated beyond the sample HDI range, and also reduced the likelihood of results being interpreted to correspond to specific countries in the sample.

## Treatment of Missing Data

Overall, 668 participants (11%) were missing household income data. Four sites had missing household income data in excess of 10%: UK (15%), Brazil (21%), Portugal (21%), and South Africa (30%). Participants missing household income data were not significantly different to those with complete household income data with respect to sex, age, obesity, MVPA, and sedentary time.

Consistent with our previous research,[6, 23] missing values for household income were analyzed as multiply-imputed data to reduce the chance of bias due to exclusion of these cases. Missing values were multiply-imputed (5 imputations) using fully conditional specification (FCS) methods, under missing at random (MAR) assumptions[24] and using SAS version 9.4 (PROC MI). Country-specific models were used to impute household income categories, which were subsequently collapsed into the four household income levels, as previously described.

## Statistical Analysis

Data analysis was conducted in 2017, to appropriately account for the multiply-imputed household income data, results from all statistical analyses were averaged across the five imputed datasets, and the standard errors were adjusted using the MIANALYZE procedure in SAS.

To assess the time spent in MVPA and sedentary time among the different levels of within-country SES we used multi-level random effects models (PROC MIXED) that accounted

for clustering at both the school and site levels. Denominator degrees of freedom for statistical tests pertaining to fixed effects were calculated using the Kenward and Roger approximation.[25] The country specific HDI and the country-specific sample household income levels have been published elsewhere.[6] For presentation, least-square means for MVPA and sedentary time were estimated separately for boys and girls at values corresponding to the previously mentioned HDI percentiles. Data are presented separately due to significant differences observed between boys and girls for both MVPA and sedentary time (data not shown).

## Results

Descriptive characteristics of the sample are provided in Table 1. The estimated least-square means for time in MVPA and sedentary time for the four SES levels at the three different HDI percentiles are presented in Figures 1 and 2 and supplemental Table S1. Values are presented as least-square mean estimates (standard error) in min/day. For boys, MVPA was negatively associated with SES at the $10^{th}$ percentile of HDI, with a difference of 16 min/day ($p<.001$) between the level 1 and level 4 SES. Although MVPA at the Level 1 SES was lower than the other levels at the $50^{th}$ percentile of HDI, there was a significant negative relationship at the $50^{th}$ percentile HDI with a difference of 3 min/day ($p<.002$) between level 2 and level 4 SES. There was no significant relationship between SES level and MVPA at the $90^{th}$ percentile HDI ($p=.152$). There was a significant positive relationship between SES and boys sedentary time only at the $10^{th}$ percentile HDI ($p=.031$). Sedentary time was 480±15 min/day at the lowest SES level and 503±15 min/day at SES level. No significant associations were found between SES and sedentary time at the $50^{th}$ and $90^{th}$ percentile HDI.

For girls, MVPA was also negatively associated with SES level in the $10^{th}$ and $50^{th}$ percentiles of HDI (with a difference between SES levels of 10 and 3 min/day, respectively, all $p<.012$). At the $90^{th}$ percentile HDI, a significant positive association between MVPA and SES

194 was observed, with a difference of 4 min/day (p=.044) between the highest and lowest SES
195 levels. No significant associations were found between SES and sedentary time for girls.

196 **Discussion**

197 The results of this study demonstrated that relationships of physical activity and
198 sedentary time with SES vary across countries that differ in level of human development. At
199 lower and middle levels of HDI, children with lower SES levels were more active than children
200 with higher SES levels. In girls, those with higher SES from countries in the 90$^{th}$ percentile HDI
201 were less active than girls with lower SES; however, this difference was not present for boys in
202 countries at the 90$^{th}$ percentile HDI. These results point to the possibility of an epidemiological
203 transition in physical activity, displaying lower levels of MVPA at opposite ends of the SES
204 spectrum depending on HDI level, especially for girls; however, this was not true for sedentary
205 time. The meaning of these findings can affect the development of multi-country physical
206 activity interventions because the targeted at-risk population may differ based on the country
207 HDI level.

208 It is difficult to place these results into the context of the existing literature because no
209 other published studies have examined the SES-HDI relationship with MVPA and sedentary time
210 in a diverse multi-county sample of children and with such rigorous and standardized
211 methodology. However, small scale studies have been conducted in some of the countries
212 included in this sample and similar results were found.[26] Difficulties also exist in determining
213 which aspects of household income or the country HDI specifically influence the amount of time
214 that children spend in these specific behaviors. It is possible that the differences found in this
215 study arise from a different mix of obligatory and discretionary physical activities. For example,
216 in some sites physical education class was mandated by the government while in others it was a
217 decision at the school level. Further, it is possible that SES can influence active transportation,

218 access to parks, other recreational activities, sports participation, and the overall view of physical
219 activity as positive for children; however, this speculation could not be tested using our data.
220 For adults in a single country study, it has been suggested that technological advances
221 associated with economic development in labor and housekeeping have led to decreases in
222 energy expenditure associated with physical activity.[2] In a multi-country adult study,[11] there
223 were variations in MVPA levels between the countries with different HDI levels without a clear
224 association between MVPA and HDI levels. In addition, in the individual countries, different
225 aspects of SES were significantly related to MVPA levels making it challenging to generalize.
226 However, in the same study,[11] the only factor that produced a similar influence across all five
227 countries was car ownership, where adult car owners were less active than those who did not
228 own cars. This suggests that access to transportation might play a role in explaining physical
229 activity levels among adults; however, the implications for children are not known.
230 The application of the theory of epidemiological transition to factors[4] other than patterns
231 of morbidity and mortality changes, is relatively new but has been successfully explored to
232 demonstrate changes in nutrition and obesity.[27, 28] We have shown results in our cross-sectional
233 sample that support the possibility of epidemiological transition for both nutrition[23] and
234 obesity.[6] Likewise, when we analyzed methods and time of active transport we showed a
235 general distribution according to active school transport for trips of less than 5 min by country
236 income level, which in turn could be associated with the physical activity epidemiological
237 transition.[29] In this current study, we present an extension of those findings, creating a clearer
238 picture of the physical activity transition that is more focused on MPVA changes.[30]
239 This study had numerous strengths, such as the economic and social diversity of site
240 locations across the world as well as widely accepted standardized methodology and equipment
241 utilized in each site. However, this study was not without limitations. The samples were mostly

limited to one city in each country which were not randomly chosen for global representation. In addition, the sample was drawn primarily from urban and suburban settings, and because we used country-level HDI values and sample-specific SES levels, results may not generalize to rural settings. Despite this, the sampling was carried out in such a manner to maximize variability in SES in each site. SES was defined as parental/guardian reported annual household income and did not include other facets that can be used to define SES. We utilized estimates of MVPA and sedentary time for different HDI levels (10, 50, and 90$^{th}$ percentile) of the sample, not at an actual country-specific HDI. While the ActiGraph has been used both for measurement of MVPA and sedentary time, there is much more evidence of its validity for MVPA measurement[21, 31, 32] and some research has indicated that it is not as accurate as the ActivPAL to measure sedentary behavior[33] as defined by the Sedentary Behaviour Research Network.[34, 35] This could be one of the reasons for the lack of relationship between sedentary time and SES at different HDI levels.

**Conclusions**

In conclusion, in this extension of our previous findings,[6, 23] we showed that the relationship between MVPA and SES is variable across different country HDI levels and sex, and this is consistent with the theory of epidemiologic transition.[1] In contrast, sedentary time was mostly unrelated to SES as indicated by parent-reported household income. Additional studies, especially longitudinal surveillance studies, are necessary to confirm these findings. This information is important for the development of multi-country physical activity/sedentary time interventions in children. It indicated that country HDI, family SES, and sex should be taken into consideration. For example, children of low SES might be targeted in countries with higher HDI while children of high SES might be targeted at in lower HDI countries. These results could also serve as an alert to promote action before unintended consequences of development negatively

affect physical activity and sedentary time in those countries undergoing early stages of economic transition.

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419

420 **Table 1.** Descriptive characteristics of International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE)
421 participants stratified by sex and study site (n=6548).

422

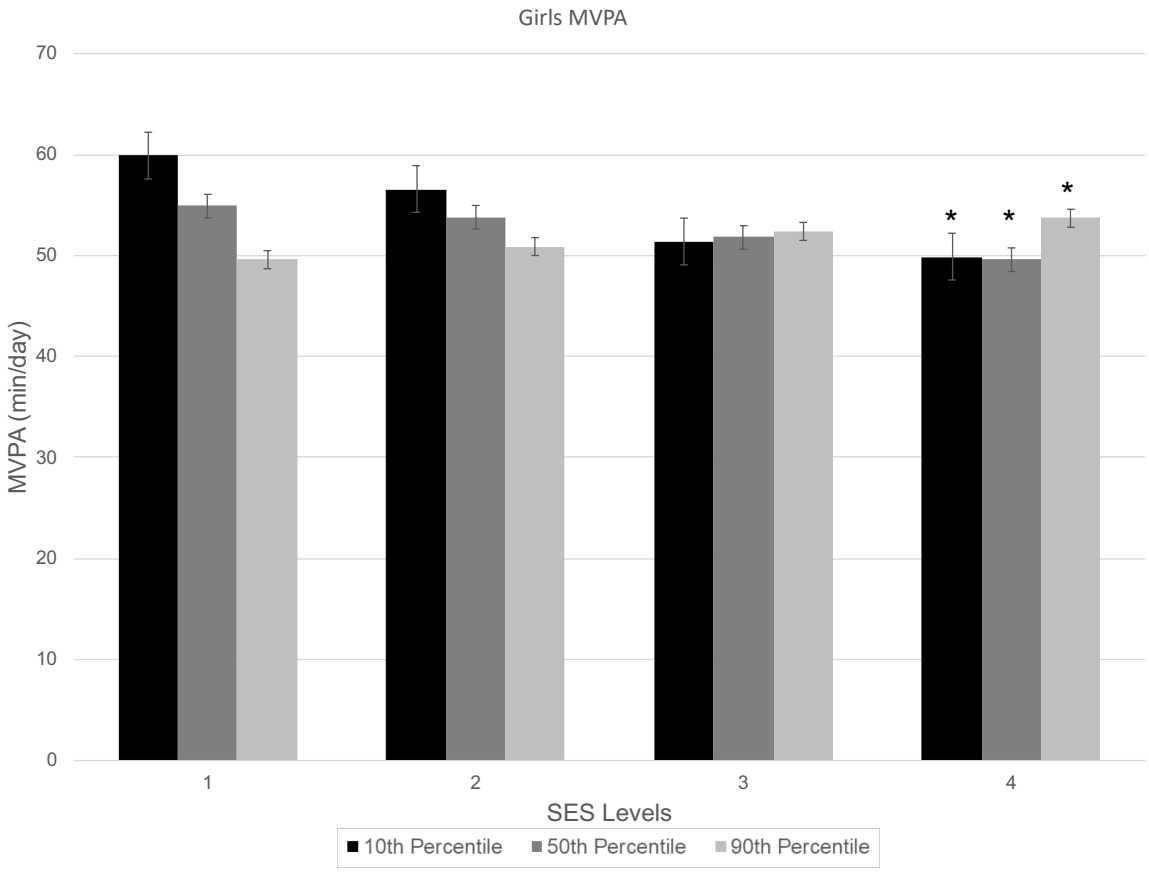
| Country (Site) | n | | Age (y) | | MVPA | | Sedentary Time | |
|---|---|---|---|---|---|---|---|---|
| | *boys* | *girls* | *boys* | *girls* | *boys* | *girls* | *boys* | *girls* |
| Australia (Adelaide) | 225 | 266 | 10.4 (0.5) | 10.3 (0.6) | 75 (24) | 57 (19) | 471 (64) | 482 (56) |
| Brazil (São Paulo) | 242 | 252 | 10.0 (0.5) | 10.0 (0.5) | 71 (28) | 48 (18) | 492 (70) | 507 (67) |
| Canada (Ottawa) | 217 | 306 | 10.1 (0.4) | 10.0 (0.4) | 67 (19) | 53 (17) | 507 (66) | 514 (61) |
| China (Tianjin) | 261 | 240 | 9.4 (0.5) | 9.4 (0.5) | 50 (16) | 41 (14) | 552 (65) | 579 (68) |
| Colombia (Bogotá) | 422 | 435 | 10.0 (0.6) | 10.0 (0.7) | 76 (26) | 60 (21) | 491 (67) | 509 (66) |
| Finland (Helsinki, Espoo & Vantaa) | 235 | 269 | 10.0 (0.5) | 10.0 (0.4) | 81 (28) | 62 (21) | 525 (71) | 534 (64) |
| India (Bangalore) | 254 | 299 | 10.0 (0.6) | 10.0 (0.6) | 62 (21) | 38 (14) | 489 (62) | 539 (62) |
| Kenya (Nairobi) | 233 | 269 | 9.7 (0.7) | 9.8 (0.7) | 81 (31) | 64 (30) | 486 (69) | 502 (62) |
| Portugal (Porto) | 305 | 381 | 10.0 (0.2) | 10.0 (0.3) | 68 (23) | 47 (15) | 537 (65) | 563 (57) |
| South Africa (Cape Town) | 184 | 284 | 9.9 (0.7) | 9.7 (0.7) | 75 (27) | 59 (23) | 480 (69) | 491 (62) |
| United Kingdom (Bath & NE Somerset) | 211 | 267 | 10.4 (0.5) | 10.4 (0.5) | 73 (24) | 56 (18) | 496 (62) | 497 (58) |
| United States (Baton Rouge) | 203 | 288 | 9.6 (0.7) | 9.4 (0.6) | 58 (20) | 44 (16) | 512 (62) | 528 (61) |

423 MVPA: moderate-to-vigorous physical activity

Figure Legend:

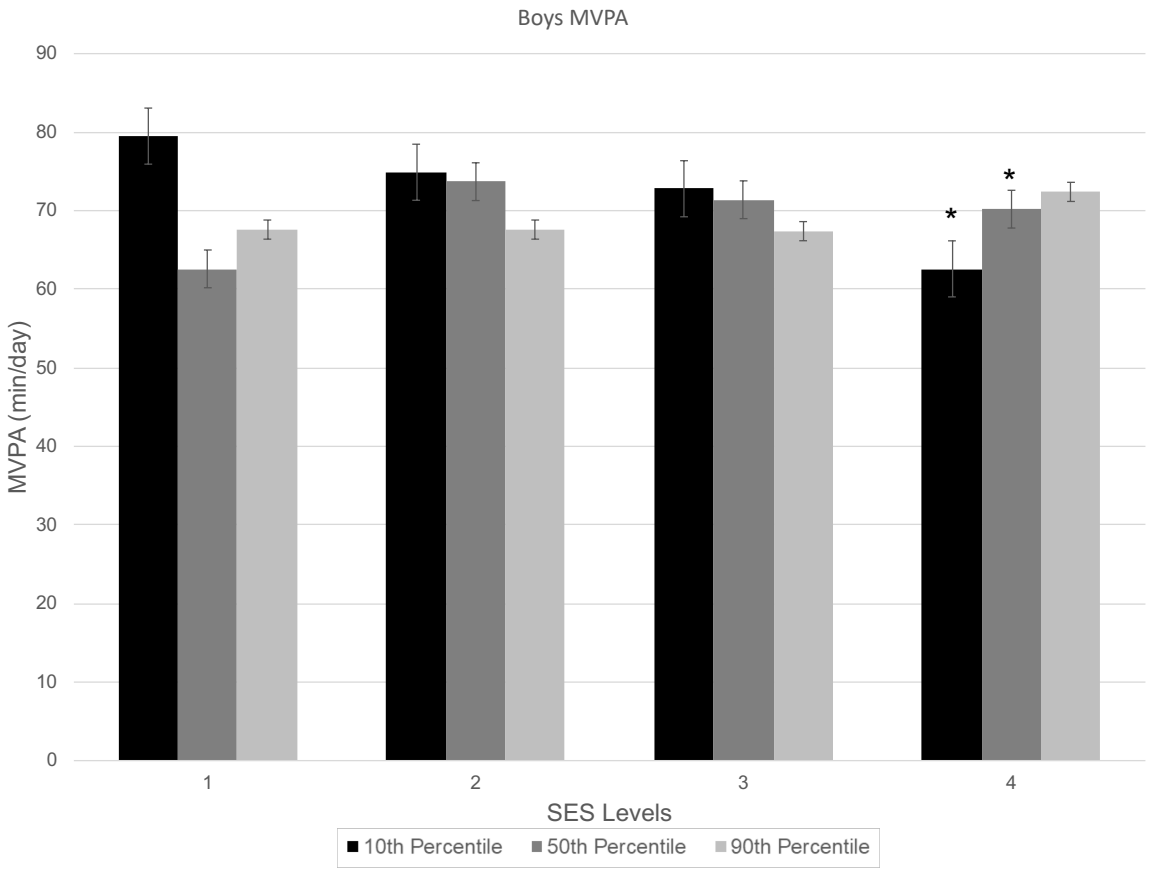
**Figure 1a and 1b** - Income gradients in moderate-to-vigorous physical activity (MVPA) across HDI levels in boys and girls. Data are shown as least-square means at HDI levels corresponding to the 10th, 50th and 90th percentiles of the ISCOLE sample (HDI=0.52, 0.72 and 0.91, respectively). Tests for linear trend are indicated: *P<0.05.

**Figure 2a and 2b** - Income gradients in sedentary time across HDI levels in boys and girls. Data are shown as least-square means at HDI levels corresponding to the 10th, 50th and 90th percentiles of the ISCOLE sample (HDI=0.52, 0.72 and 0.91, respectively). Tests for linear trend are indicated: *P<0.05.


Girls MVPA
70
60
50
40
30
20
10
0
MVPA (min/day)
1
2
3
4
SES Levels
10th Percentile
50th Percentile
90th Percentile
*
*
*

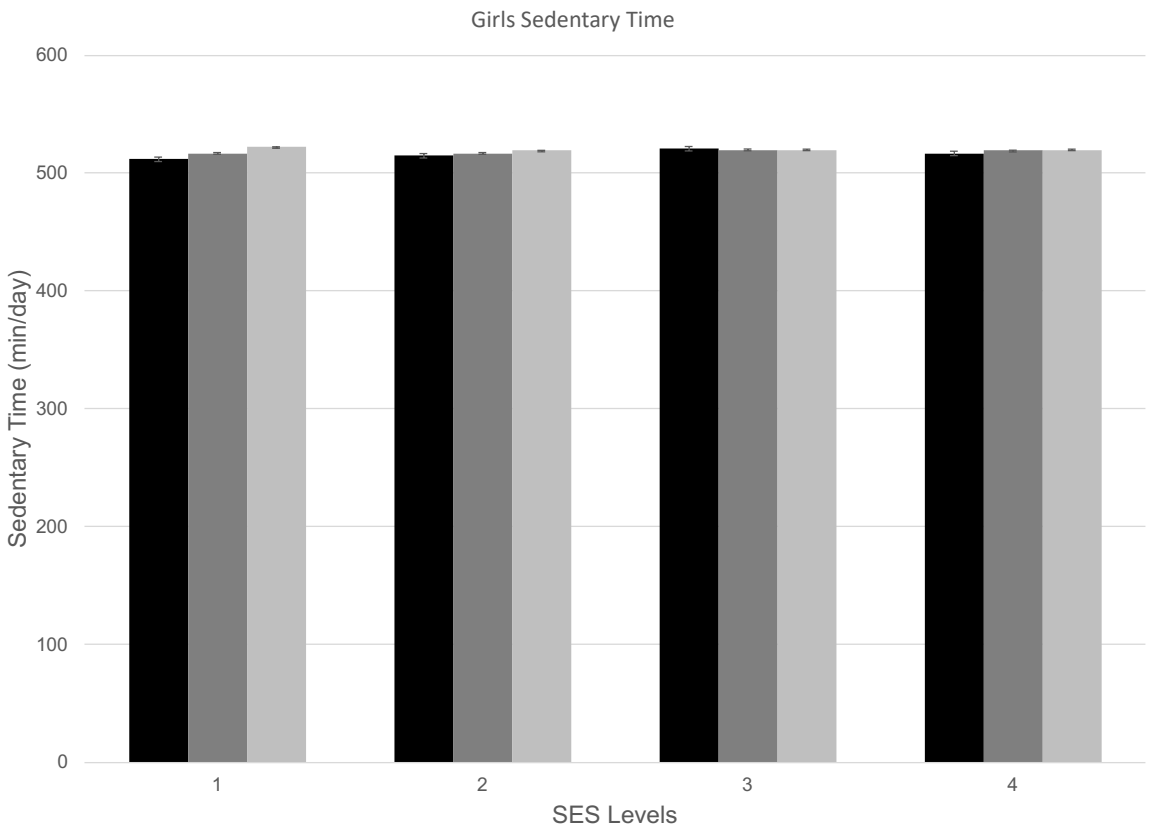
434

435

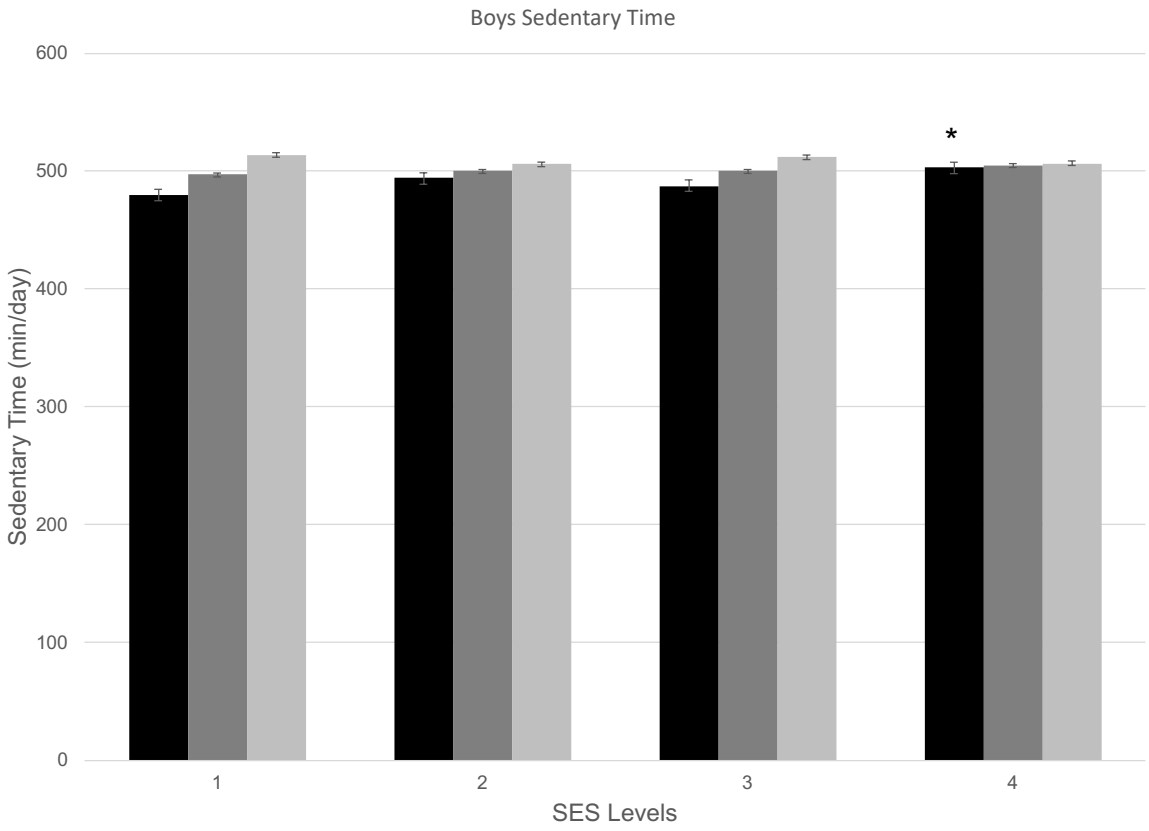

Boys MVPA
MVPA (min/day)
90
80
70
60
50
40
30
20
10
0
1
2
3
4
SES Levels
10th Percentile
50th Percentile
90th Percentile
*
*

436

437


Girls Sedentary Time
600
500
400
300
200
100
0
Sedentary Time (min/day)
1
2
3
4
SES Levels

438


Boys Sedentary Time
600
500
400
300
200
100
0
Sedentary Time (min/day)
*
1
2
3
4
SES Levels

439

440

**Table 2.** Boy's least-square mean estimates[1] for measures of accelerometer derived physical activity and sedentary time across country-specific income levels and human development index (HDI): the International Study of Childhood Obesity, Lifestyle, and the Environment (ISCOLE).

| Socio-economic Status | Level 1 (low) | Level 2 | Level 3 | Level 4 (high) | p for trend[2] |
|---|---|---|---|---|---|
| | | *Boys* | | | |
| ISCOLE 10th percentile of HDI | | | | | |
| Sedentary time | 480 (15) | 494 (15) | 488 (15) | 503 (15) | 0.031 |
| MVPA | 79.5 (5.6) | 74.9 (5.6) | 72.8 (5.6) | 62.6 (5.6) | <0.001 |
| ISCOLE 50th percentile of HDI | | | | | |
| Sedentary time | 497 (8) | 500 (8) | 500 (8) | 505 (8) | 0.117 |
| MVPA | 62.6 (2.9) | 73.7 (3.0) | 71.4 (2.9) | 70.2 (2.9) | 0.002 |
| ISCOLE 90th percentile of HDI | | | | | |
| Sedentary time | 514 (12) | 506 (12) | 512 (12) | 507 (12) | 0.510 |
| MVPA | 67.6 (4.5) | 67.6 (4.4) | 67.4 (4.4) | 72.4 (4.4) | 0.152 |

[1] Least-square mean estimates of activity and sedentary measures at HDI levels corresponding to the 10th, 50th, and 90th percentiles of the ISCOLE country sample (HDI=0.52, HDI=0.72, and HDI=0.91, respectively).

[2] Test for linear trend (linear contrast) across the four income levels

MVPA: moderate-to-vigorous physical activity

Values are presented as mean (standard error) for min/day

464 **Table 3.** Girl's least-square mean estimates[1] for measures of accelerometer derived physical
465 activity and sedentary time across country-specific income levels and human development
466 index (HDI): the International Study of Childhood Obesity, Lifestyle, and the Environment
467 (ISCOLE).

468

| Socio-economic Status | Level 1 (low) | Level 2 | Level 3 | Level 4 (high) | p for trend[2] |
|---|---|---|---|---|---|
| ISCOLE 10th percentile of HDI | | | | | |
| Sedentary time | 512 (18) | 515 (18) | 521 (18) | 517 (18) | 0.354 |
| MVPA | 59.9 (4.9) | 56.6 (4.9) | 51.4 (4.9) | 49.9 (4.9) | <0.001 |
| ISCOLE 50th percentile of HDI | | | | | |
| Sedentary time | 517 (9) | 517 (9) | 520 (9) | 519 (9) | 0.456 |
| MVPA | 54.9 (2.6) | 53.8 (2.6) | 51.8 (2.6) | 49.6 (2.6) | 0.012 |
| ISCOLE 90th percentile of HDI | | | | | |
| Sedentary time | 522 (14) | 519 (14) | 520 (14) | 520 (14) | 0.839 |
| MVPA | 49.6 (0.12) | 50.9 (0.11) | 52.4 (0.12) | 53.7 (0.12) | 0.044 |

469 [1] Least-square mean estimates of activity and sedentary measures at HDI levels corresponding to the
470 10th, 50th, and 90th percentiles of the ISCOLE country sample (HDI=0.52, HDI=0.72, and HDI=0.91,
471 respectively).

472 [2] Test for linear trend (linear contrast) across the four income levels

473 MVPA: moderate-to-vigorous physical activity

474 Values are presented as mean (standard error) for min/day

475